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DoD Corrosion Prevention and Control Program

Demonstration of a Robust Sensor System for Remote Condition Monitoring of Heat-Distribution System Manholes

Final Report on Project F09-AR03

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Final report

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Under Project F09-AR03, “Design and Implementation of Robust, Remote, Wireless Heat Distribution System Sensors for Monitoring Extremes of Heat and Humidity”

Abstract

This project demonstrated a wireless remote-monitoring system for detecting and reporting steam leaks or flooding in underground heat-distribution system (HDS) manholes. The system immediately notifies maintenance personnel of critical conditions that could indicate expensive energy losses and potentially serious damage to the HDS. Demonstrated at Redstone Arsenal, AL, the system used durable temperature and water-level sensors for operating in very high heat and humidity. Remote-monitoring nodes included remote transmitting units using one of two alternate wireless data technologies. Wireless 900 MHz Ethernet service was installed and commissioned for eight manholes, linking them to the Redstone supervisory control and data acquisition (SCADA) system, but full integration with the SCADA system was not feasible given limitations on installation resources. Cellular data service was installed for six other manholes and commissioned successfully. Those nodes functioned for about 15 months to record ambient manhole conditions and email daily rollup data to the project point of contact (POC), verifying continuous operation.

The functionality of the system design was validated, but important lessons were learned about electric service availability, line-of-sight antenna positioning for wireless Ethernet, and RTU installation. The return on investment for the cellular system was 94.6, potentially saving $534,000 in maintenance over 30 years.

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Preface

This demonstration was performed for the Office of the Secretary of Defense (OSD) under Department of Defense (DoD) Corrosion Control and Prevention Project F09-AR03, "Design and Implementation of Robust, Remote, Wireless Heat Distribution System Sensors for Monitoring Extremes of Heat and Humidity." The proponent was the U.S. Army Office of the Assistant Chief of Staff for Installation Management (ACSIM), and the stakeholder was the U.S. Army Installation Management Command (IMCOM). The technical monitors were Daniel J. Dunmire (OUSD(AT&L)), Bernie Rodriguez (IMPW-FM), and Valerie D. Hines (DAIM-ODF).

The work was performed by the Engineering and Materials Branch of the Facilities Division (CEERD-CFM), U.S. Army Engineer Research and Development Center – Construction Engineering Research Laboratory (ERDC-CERL), Champaign, IL. At the time this report was prepared, Vicki L. Van Blaricum was Chief, CEERD-CFM; L. Donald K. Hicks was Chief, CEERD-CF; and Kurt Kinnevan, CEERD-CZT, was the Technical Director for Adaptive and Resilient Installations. The Deputy Director of ERDC-CERL was Dr. Kirankumar Topudurti and the Director was Dr. Ilker Adiguzel.

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- Timothy J. Smith, USA IMCOM
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COL Bryan S. Green was the Commander of ERDC and Dr. Jeffery P. Holland was the Director.

Executive Summary

This Corrosion Prevention and Control Program project demonstrated the use of robust sensors in a real-time remote-monitoring system that will operate effectively in the high temperatures and humidity inside heat-distribution system (HDS) manholes. A prototype system was designed and installed in two sets of HDS manholes at Redstone Arsenal, AL. Its purpose was to detect spikes in manhole ambient temperature or water levels that may indicate a critical problem, such as the sudden release of pressurized carrier fluid from a steam leak. Water detected near the lowest elevation of any distribution piping may indicate a problem such as sump pump failure. Either type of problem may be caused by or result in severe corrosion of steel HDS components, and must be corrected immediately to avoid costly collateral impacts on energy costs or HDS infrastructure.

Each set of manholes was equipped with remote transmitting units (RTUs) using a different wireless communications technology—either cellular telecommunications (Global System for Mobile Communications standard, or GSM) or wireless Ethernet linked to the installation supervisory control and data acquisition (SCADA) network using standard 900 MHz radio-frequency connectivity. This technical report documents the installation, configuration, and commissioning of the prototype manhole monitoring system. It presents monitoring data collected through the performance period and provides an economic analysis of one representative technology implementation. Data indicate that the system can provide effective continuous monitoring with minimal labor requirements.

The project validated the application of this system design to remotely monitor the operating conditions in HDS manholes. Lessons learned included the need to verify electric service to manholes before designing an installation-wide system; and antenna-siting considerations when using 900 MHz radio-frequency communications. Also, a cellular communications link is probably preferable in order to work around an installation's competing priorities for the base SCADA system. The return-on-investment (ROI) calculation for the cellular-system design was calculated at 94.6, roughly $534,000 over 30 years. The ROI for the SCADA-based design was slightly lower, but is less practical without full higher-level coordination on SCADA system priorities and communication security.

Unit Conversion Factors

Multiply	By	To Obtain
degrees Fahrenheit	(F-32)/1.8	degrees Celsius
feet	0.3048	meters
gallons (U.S. liquid)	3.785412 E-03	cubic meters
inches	0.0254	meters
mils	0.0254	millimeters
square feet	0.09290304	square meters

1 Introduction

1.1 Problem statement

The Department of Defense (DoD) is the largest operator of district heating systems. When functioning properly, these are cost effective and allow for the adaptive contingency of fuel switching at the central boiler plant. District heating systems require considerable expense to build and maintain, however, typically costing $750 – $1,000 per foot of piping plus ongoing operational costs to heat water and supply it to buildings (Marsh 1998). The heat-distribution system (HDS) consists of a network of steel pipes, valves, and appurtenances. In below-grade systems, these components are accessed for maintenance through below-grade manholes (also called *valve pits*). The environment in HDS manholes is hot and humid during normal operation. Often, due to the failure of sump pumps and/or the leakage of carrier fluid, manholes become flooded with water (Figure 1). When this occurs, pipe insulation is defeated and heat is transferred out of the HDS due to continuous boiling inside the manhole. At very least, this wastes a considerable amount of energy, estimated conservatively to cost $50,000 – $125,000 per year (Marsh 1998).

Figure 1. Continuous manhole boiling caused by submerged HDS piping.

Flooded manholes also create optimal conditions for aggressive and accelerated corrosion. As degradation accelerates, it can quickly lead to component failure and safety hazards. Figure 2 and Figure 3 show examples of

accelerated corrosive degradation caused by the ingress of water into manholes.

Figure 2. Accelerated corrosive degradation caused by manhole flooding.

Figure 3. Accelerated corrosive degradation from manhole flooding, including severe damage to insulation, insulation sheathing, and carrier pressure piping.

Figure 4 shows a failed valve body, which could scald or asphyxiate a manhole inspector. Depending on metal thinning around the steam jets shown in the figure, such a leak could greatly increase at any random time.

Figure 4. Leaking valve body in pressurized HDS, posing burn and asphyxiation hazard to system maintenance personnel.

If any severe degradation continues undetected or unrepaired, the performance of the entire HDS is compromised; problems can propagate from a single manhole to become systemic. If problems become too widespread to address with ad hoc work plans, the HDS becomes unsustainable. An early system replacement will be necessary, representing an avoidable excess expense for the responsible installation.

Preventing accelerated severe HDS corrosion requires proactive monitoring of manhole conditions. The manpower needed for scheduled onsite inspection is expensive, and installations may not have enough personnel to serve as qualified inspectors. An effective and affordable alternative might be the application of a remote-monitoring system capable of sensing off-specification heat and humidity extremes and reporting them in near-real time to installation maintenance personnel. The sensors and other monitoring components would have to be robust enough to operate reliably under both normal manhole conditions and through the extremes of heat and humidity that would occur in the event of steam line perforation due to corrosion or when the manhole floods.

A Corrosion Prevention and Control (CPC) demonstration project was executed to design, install, and evaluate a robust HDS remote-monitoring system at Redstone Arsenal, AL, where the HDS conveys 380 °F saturated steam at 180 pounds per square inch gage (psig).

1.2 Objective

The objective of this demonstration was to design, install, and evaluate a remote-monitoring system with robust sensors capable of withstanding temperature and humidity extremes in HDS manholes and providing timely, accurate data to maintenance personnel.

1.3 Approach

In this project, the term *robust* means that both types of sensors can withstand 100% relative humidity at temperature extremes of up to 300 °F, which represent the extremes of what could occur a inside damaged or failed HDS manhole. Temperature and water-level sensors meeting that specification were selected and installed in 16 Redstone Arsenal steam pits.

The sensors were interfaced with two different wireless communication technologies. Eight steam pits were monitored using GSM* cellular telecommunication technologies. In those pits, the system included a GSM-based remote transmitting unit (RTU) that was programmed to send an email alert whenever water was detected in the pit or when the temperature exceeded a predefined threshold. In the other eight pits, the system incorporated Ethernet-based RTUs wirelessly interfaced with the installation's Supervisory Control and Data Acquisition (SCADA) network. The SCADA network operates on a wireless 900 MHz line of sight Ethernet network, with a central antenna located on the installation at Madkin Mountain.

Sensor data was communicated by wireless link to a central location. For each manhole, multiple sensors were used to monitor ambient temperature and detect the level of any standing water. The detected presence of water indicates possible problems with system leakage and/or sump pump operation. A sensor near the lowest leg of the distribution piping flags a standing-water situation that requires immediate attention; a second sensor detects rising water, indicating that a serious problem is in progress. Ambient temperature readings are taken for confirmatory purposes and to alert maintenance personnel to the sudden release of pressurized carrier fluid, as occurs in a blown steam trap, catastrophic valve packing leak, etc.

* GSM: Global System for Mobile Communications (telecommunications protocol standard).

2 Technical Investigation

2.1 Technology overview

2.1.1 Sensors

2.1.1.1 RTD temperature sensors

The temperature sensors chosen were Series 68 resistance temperature detectors (RTDs) manufactured by Emerson Rosemount Measurement Division[*] (see Figure 5) These sensors are rated for operation between -58 and 752 °F.

Figure 5. RTD temperature sensor. (Note: the pictured PVC piping was used in the manhole only in the proof-of-concept testing.)

RTD temperature sensors operate by taking advantage of the predictable nature of the change in electrical resistance of some materials (in this case, platinum) as temperature changes. The Series 68 RTD has a nominal resistance of 100 ohms. The RTD element is encased in a AISI 316 stainless

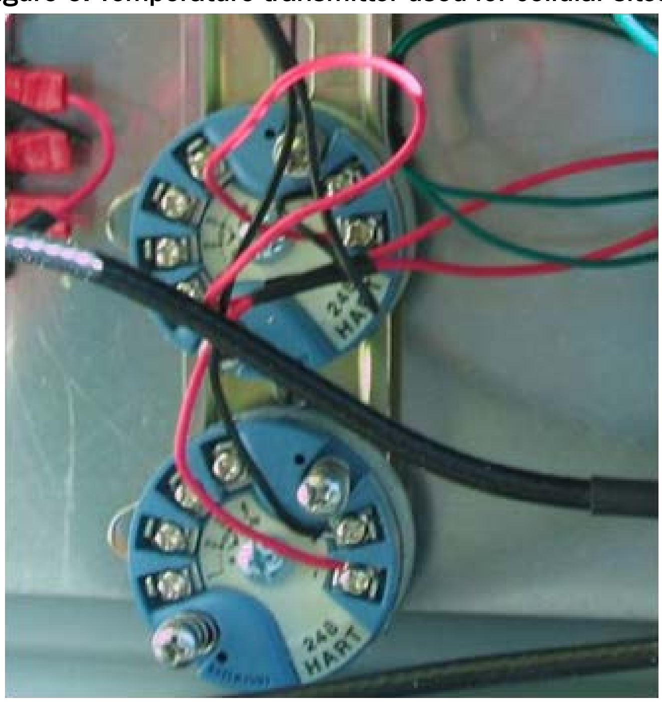
[*] Emerson Rosemount Measurement Division, 8200 Market Blvd., Chanhassen, MN 55317.

steel sheath in order to provide durability and corrosion resistance. The sensor leads are American wire gauge (AWG) 22 nickel-plated copper wire. As the RTD is, in effect, a precision resistor, polarity is not a concern; the RTD may be wired in the monitoring circuit without regard for which lead is connected to signal or which lead is connected to ground. The configuration of the Series 0068 RTDs chosen for this project includes 0.5 in. NPT threads for attachment to standard piping.

2.1.1.2 Temperature transmitters

The RTU chosen for the SCADA pits is capable of reading the chosen RTD sensors directly, but the RTU for the cellular pits is not. For the cellular pits, a temperature transmitter is necessary. The transmitter is a piece of equipment that connects to the sensor, reads the temperature, and converts it to a 4 – 20 mA analog signal which can be read through a standard analog input. A Rosemount 248 temperature transmitter from Emerson Rosemount Measurement Division* was selected for this project (see Figure 6). Because the temperature transmitters are not as rugged or corrosion resistant as the RTD assemblies, they were located inside an enclosure mounted outside the pits.

Figure 6. Temperature transmitter used for cellular sites.



* Emerson Rosemount Measurement Division, 8200 Market Blvd., Chanhassen, MN 55317.

2.1.1.3 Float switches

In order to detect the presence of water in the pits, float switches were installed. One switch was installed at the bottom of each pit (no farther than 6 in. from the bottom of the pit). This switch was intended to provide an initial warning when water begins accumulating in the pit. A second switch was installed 24 in. from the bottom of the pits. This is intended to provide a final warning before pipes or valves begin to be submerged. A miniaturized float switch (FS11-001) from SMD Fluid Controls* was chosen for this application (see Figure 7). The switch is constructed from AISI 304 stainless steel for temperature and corrosion resistance. The switch has 0.125 in. pipe threads for mounting, and the lead wires are AWG 22 copper wires with a PTFE coating, and can operate at temperatures up to 125 °C (257 °F) and pressures up to 75 psig (517.1 kPA).

Figure 7. Float switch.

2.1.2 Remote transmitting units (RTUs)

For electronic devices exposed to high ambient heat, a common problem is a reduction in signal/noise ratio; that is, noise increases when temperature

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* SMD Fluid Controls, 55 Barnes Park Road, North Wallingford, CT 06492.

rises beyond a specified threshold. Signal-processing robustness in terms of good signal/noise ratio were a key criterion in equipment selection.

2.1.2.1 Ethernet RTUs

The RTU chosen for the SCADA-monitored pits was the SEL-2411 from Schweitzer Engineering Laboratories (SEL)*. The SEL-2411 was chosen because it has sufficient digital inputs to read the float switches, and is capable of interfacing directly with the RTD temperature sensors (see Figure 8). In addition, the existing electrical control equipment on Redstone Arsenal's SCADA network is manufactured by SEL, so personnel were already familiar with that brand of equipment. Finally, it possesses a built-in Ethernet port that allows it to interface with the Ethernet radio used for Redstone Arsenal's SCADA network.

Figure 8. RTU for manholes monitored by the SCADA system.

The SEL-2411 configuration chosen for this project (p/n SEL-241101A0X9X0X0X0130) features ten RTD inputs and two digital inputs. In addition, it features a front-mounted serial port for easy programming, and an RJ-45 Ethernet port for connection to the Ethernet radio.

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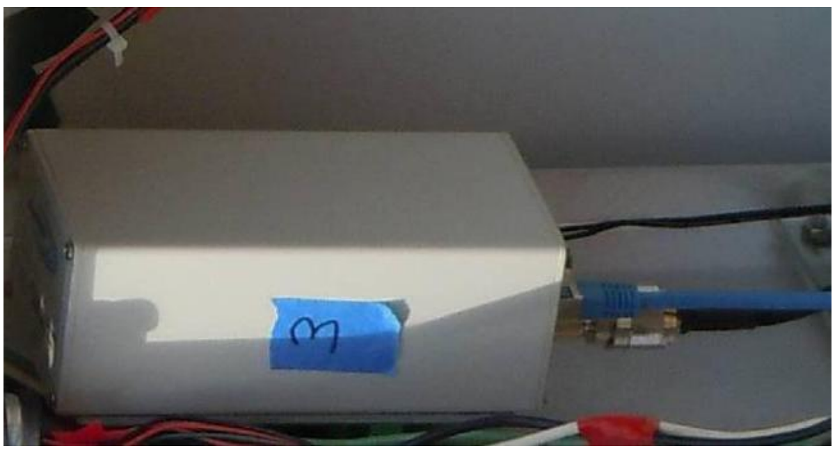
* Schweitzer Engineering Laboratories, 2350 NE Hopkins Court, Pullman, WA 99163.

The SEL-2411 is programmed using AcSELerator, a proprietary application developed and provided by SEL. AcSELerator is available to the public free of charge, and is capable of interfacing with all of SEL's equipment.

The SEL-2411 communicates with Redstone Arsenal's network through a 900-MHz line of sight Ethernet radio manufactured by Freewave, Inc* (see Figure 9). The HTP-900RE is capable of transferring Ethernet data over a distance of up to 15 miles with a clear line of sight, and is programmable through a standard web browser. It was chosen primarily because it is in use as the radio for Redstone's other SCADA-connected equipment, so compatibility with their network was assured.

Figure 9 Ethernet radio used at SCADA site.



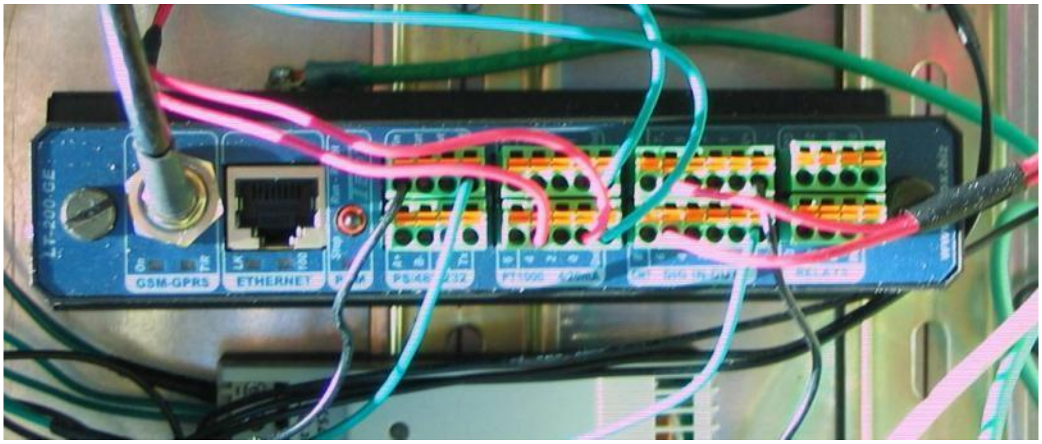
2.1.2.2 Cellular RTUs

For the cellular remote-monitoring phase of the project, the T-Box Lite from CSE Semaphore Inc.† was chosen (see Figure 10). Although the T-Box is capable of interfacing with a SCADA system, it was chosen for this application because it has an integrated GSM (cellular) modem. With this modem, the T-Box Lite can be configured to send emails or SMS messages directly to the party responsible for monitoring without routing through a central monitoring station as used in a SCADA system.

* Freewave, Inc., 1880 S Flatiron Court, Suite F, Boulder, CO 80301.

† CSE Semaphore, Inc., 1200 Chantry Place, Lake Mary, FL 32746.

Figure 10. T-Box Lite unit used for monitoring at sites using cellular communication.



The T-Box Lite has eight digital input/output pins, six analog inputs (4 – 20 mA), and two RTD temperature inputs. Although the device is capable of directly interfacing with RTD temperature sensors, it requires a base resistance of 1000 ohms. Since the sensors used for this project have a base resistance of 100 ohms, they were not compatible with these inputs, and were connected to the Rosemount 248 temperature transmitter. The transmitter converted the RTD signal into a 4 – 20 mA analog signal that could be read by the analog inputs on the T-Box Lite.

2.1.3 Unit enclosures

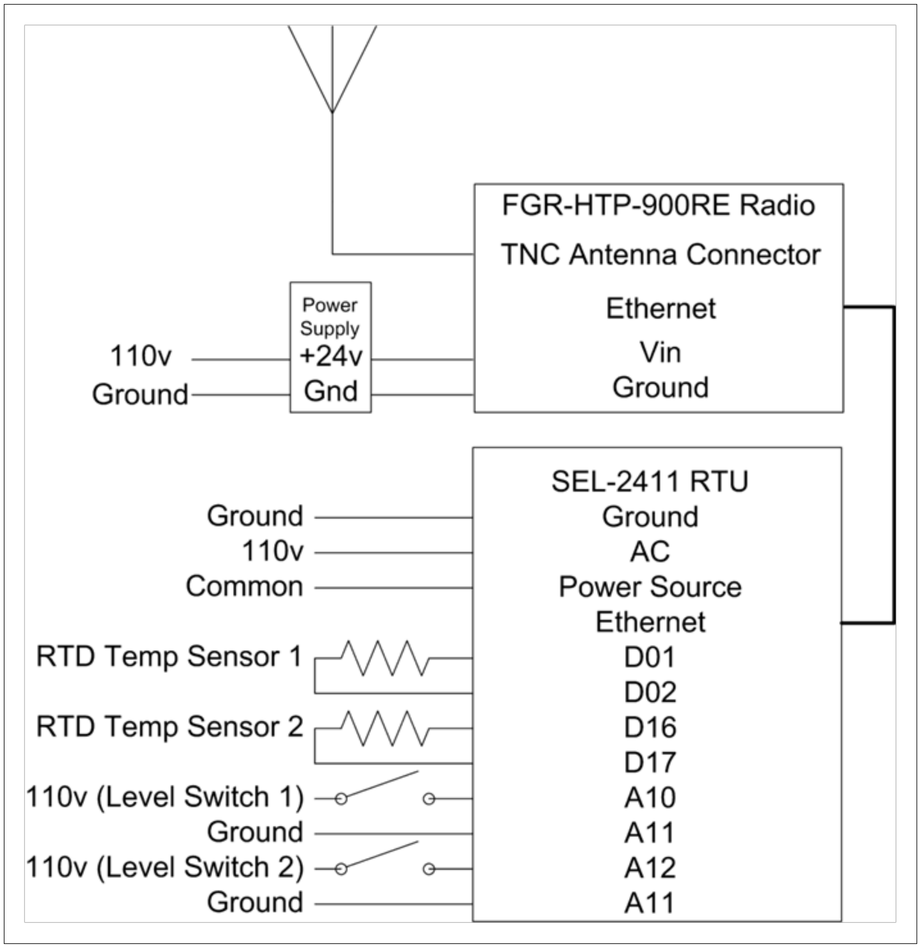
The SEL-2411 and T-Box Lite are both mounted in weatherproof NEMA-rated enclosures. The SEL-2411 was supplied with an enclosure with generous amounts of interior space. The T-Box Lite was not supplied with an enclosure, so one had to be sourced and procured.

2.1.4 Wiring diagrams

2.1.4.1 SCADA wireless Ethernet

The wiring diagram for the SCADA system is shown in Figure 11. The SEL-2411 RTU is powered directly by 110 volts alternating current (AC) and does not require an external power supply. The RTD temperature sensors are connected directly to the RTD inputs. The first sensor is connect to ports D01 and D02. The second RTD sensor is connected to ports D16 and D17. Since RTD temperature sensors are not polar devices, either lead from the RTD sensors can be connected to either of the RTD ports.

Figure 11. SCADA system wiring diagram.



In order to monitor the level switches, a 110 volt circuit must be created. The level switches are wired to a hot 110 volt connection on one end, and the digital input port on the other end. The lower switch is connected to port A10 on the RTU, and the upper switch is connected to port A12. Port A11 is connected to ground in order to create an open circuit. When the water level rises, the switch closes, completing the circuit and informing the RTU that the water level in the pit has risen past that particular switch. As with the RTD sensors, the level switches are not polar devices, and either lead may be connected to either side of the circuit.

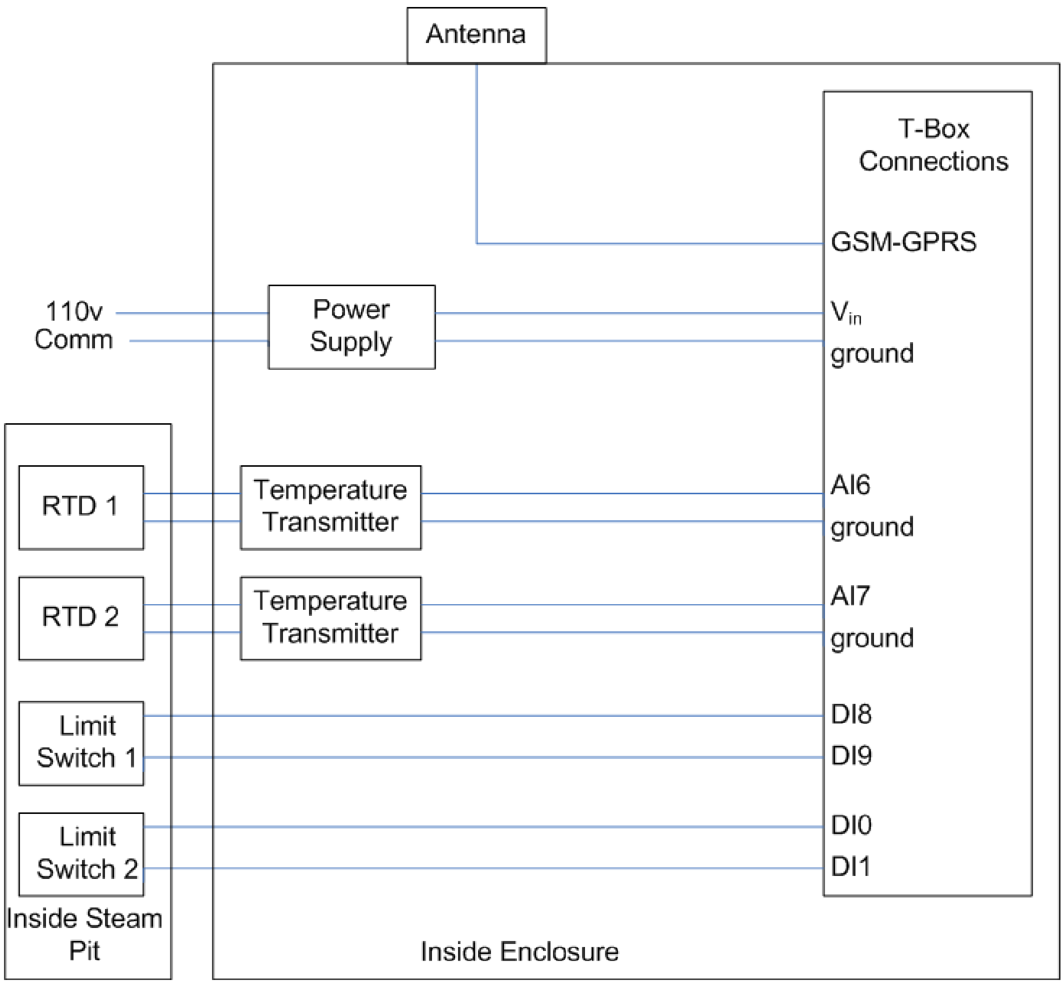
The RTU is connected to the FGR-HTP-900-RE radio by a short Ethernet patch cable. The radio is powered through an external power supply, and is connected to an externally mounted Yagi directional antenna (see also section 3.2). The connection to the antenna is made through a bulkhead connector mounted in the bottom of the enclosure. The radio is pro-

grammed with the necessary information (IP address, and transmit and receive settings) to communicate on Redstone Arsenal's SCADA network.

2.1.4.2 Cellular

The wiring diagram for the cellular system is shown in Figure 12. The T-Box Lite is powered by 24 volts direct current (DC) and thus requires a power supply powered by the 110 volt AC service in the steam pits.

Figure 12. Wiring diagram for cellular system.



Because the T-Box Lite is configured to read 1000-ohm RTD sensors instead of 100-ohm sensors, the temperature sensors first had to be connected to transmitters, which generated a 4 – 20 mA analog signal. The lower sensor was connected to a transmitter which was connected to Analog Input (AI) 6, and to ground. The upper sensor was connected to AI7 and to ground. The temperature transmitters are polar devices, and re-

versing their ports on the T-Box will result in a negative temperature reading.

The T-Box is capable of monitoring the level switches without the need to supply external power to the circuit. As a consequence, switches can be connected directly to the digital inputs on the T-Box. The lower switch was connected to terminals DI0 and DI1, and the upper switch was connected to terminals DI8 and DI9.

2.2 Field work

2.2.1 Design concept

2.2.1.1 Temperature measurement

Temperature measurement was accomplished by two Rosemount 0068 RTD (Resistance Temperature Detection) temperature sensors connected to two Rosemount 248 temperature transmitters configured in a 4 – 20 mA loop. In order to isolate the transmitters from the harsh steam pit environment, they were mounted in an enclosure outside of the steam pit.

RTD temperature sensors work by measuring the change in electrical resistance of a material as temperature changes. They offer a number of compelling benefits compared to traditional thermocouple-based temperature measurements. They offer higher accuracy, better long-term stability, more linear behavior over the target temperature range, and they are less susceptible to electrical noise in the wiring.

2.2.1.2 Liquid detection

Liquid detection was accomplished using Rosemount 2120 Vibrating Fork Level Switches. The switches contain a relay which will be activated when the vibrating fork is submerged in condensate. During operation, the fork is constantly vibrating at its natural frequency. When the fork is submerged in liquid, the resulting change in the vibration frequency is detected and causes the internal relay to close (or open, depending on the configuration of the sensor). In addition to configuring whether the relay opens or closes upon liquid detection, the delay is also adjustable. In this case, the delay will be set to 10 seconds (relay will close 10 seconds after the fork is submerged).

This was intended to help minimize false positives caused by any other interference with the fork's vibration. In addition, the fork was surrounded by a cage-type barrier in order to prevent debris from coming into contact with the vibrating fork and causing false positives.

2.2.2 Installation

Wiring diagrams for the sensors and transmitters are shown in Figure 13 and Figure 14.

Figure 13. Temperature, level, and communications wiring.

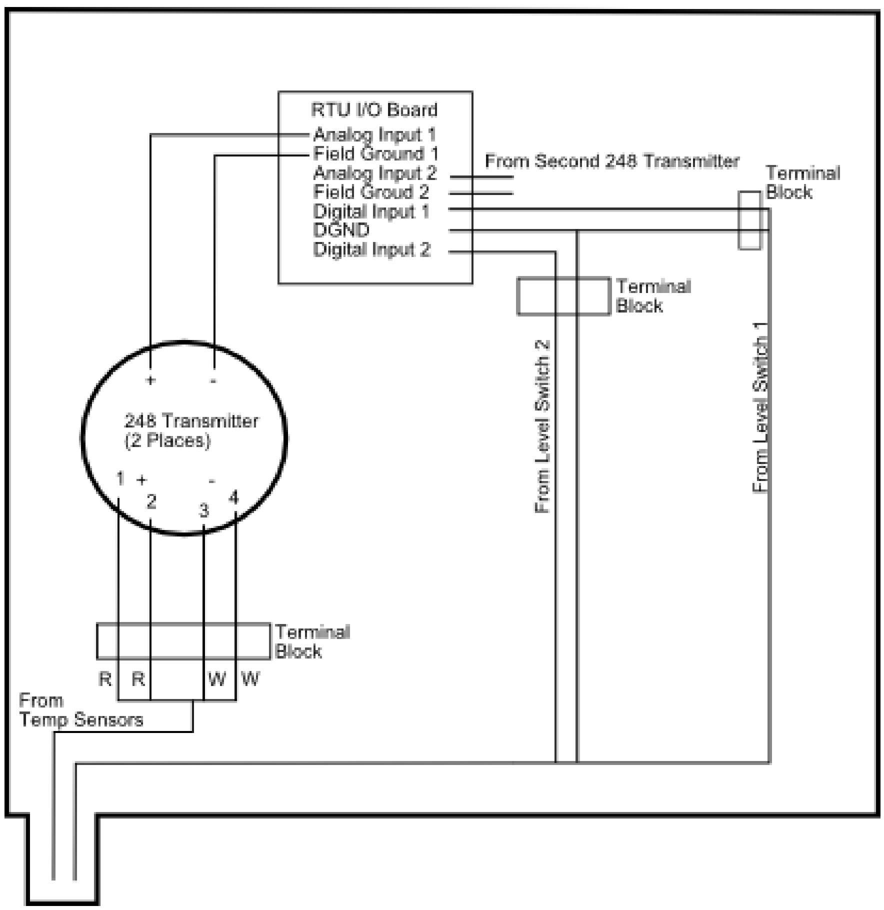
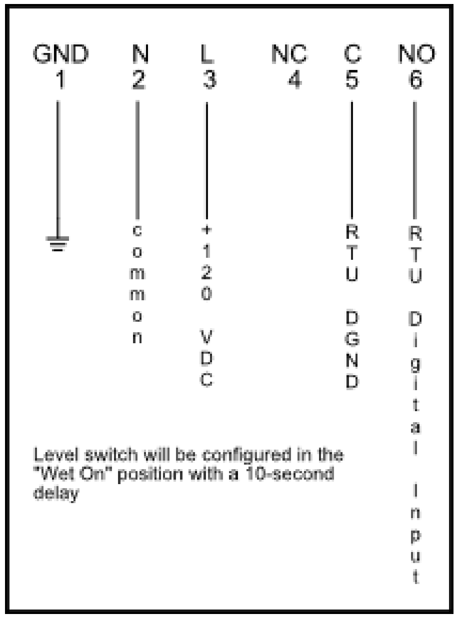
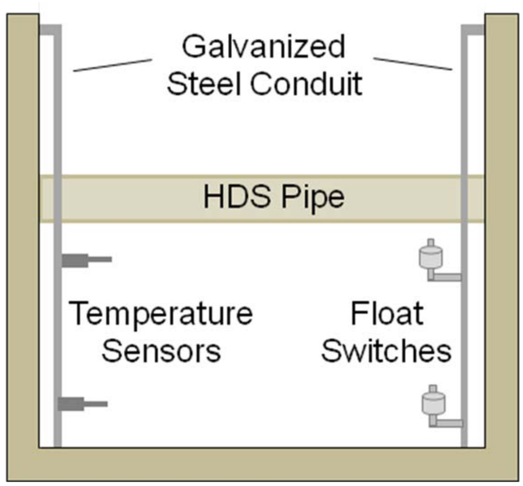


Figure 14. Wiring for level switch.



One pair of temperature and liquid sensors was mounted near the bottom of the steam pit (within 6 in. of the sump level) in order to provide early detection in the event of a sump failure. The second pair was mounted at a point slightly below the lowest steam pipe, condensate pipe, or conduit in the pit to issue the final warning submersion of the steam pipes. A diagram of the installation is shown in Figure 15.

Figure 15. Steam pit layout.



All wiring was enclosed in watertight conduit or pipe. The pipe or conduit was configured such that any moisture intrusion is channeled away from the sensors and toward low points where it can be drained if necessary.

The temperature transmitters were mounted inside the communications enclosure with the RTU and power hardware. This protected them from exposure the temperature and moisture potentially present in the steam pit. Because the control electronics for the vibrating fork level switch cannot be separated from the fork, their housing was encased in a watertight junction box to provide additional protection from the steam pit environment.

Because connecting to the SCADA network requires a line of sight to the repeater antenna on Madkin Mountain, located toward the center of the arsenal, such locations were used for the SCADA-connected pits. The remaining pits were set up with GSM cellular technology. Dig permits had to be obtained for each pit site because it was necessary to install a post in the ground for mounting the enclosures and, for the SCADA RTUs, wireless Ethernet antennas.

The next step was installing the temperature sensors in the pits. Because the temperature sensors had NPT pipe threads cut into their stainless steel casing, it facilitated mounting them onto galvanized steel pipe (see Figure 16). The sensor leads where threaded through the pipe, and the sensors were screwed into the end of the pipe (after doping compound was applied to the threads). Because of the difficulty of accessing some of the pits (due to crowding, confined-space entry issues, or lack of ladder access), the pipe was designed in such a way that it could be installed without entering the pit. One end of the pipe was capped, and the sensors were installed on tee fittings near that end (see Figure 17). This end of the pipe was placed on the pit floor. Near the other end of the pipe, also attached to a tee fitting, a flange was installed. The flange was attached to the pit wall (see Figure 18). This left an open pipe within reach of the top of the pit, with sensor leads

Figure 16.Temperature sensor wires routed into galvanized steel piping.

Figure 17. Temperature sensors installed in capped galvanized pipe.

Figure 18. Flange mounting to wall.

Once the flange was attached to the pit wall, a conduit run was installed to connect the sensor mount to the RTU enclosure, which was installed on a pole outside the pit (see Figure 19).

Figure 19. RTU unit enclosure mounted to pole.

For the SCADA pits, directional Yagi antennas were mounted on the top of the poles used for mounting the enclosure, and visually aligned with the SCADA repeater on Madkin Mountain (see Figure 20).

Figure 20. Yagi antenna used for SCADA communications.

2.3 Commissioning and monitoring

2.3.1 SCADA-networked manholes

System commissioning addressed the two communication technologies used in the steam pits to record and transmit sensor data to a designated point of contact. As noted previously, in eight test pits, the sensors were interfaced with Redstone's SCADA network via a 900 MHz wireless Ethernet link; in the other eight pits, the sensors were interfaced with GSM cellular boards.

To commission the wireless Ethernet links, the project contractor was able to connect to the Redstone SCADA network and alert the master station from each pit. In addition, a Redstone operations contractor was able to manually query a test pit and read temperatures from through the wireless Ethernet RTU.

2.3.2 Cellular-networked manholes

The GSM cellular RTUs were programmed to send notification emails to a predefined address when heat or level alarm was triggered. Alarms were sent when either installed level switch was closed or when either temperature sensor read a temperature above 180 °F (82.2 °C). Email notifications were sent to the Mandaree contractor, who would then notify the ERDC-CERL project manager, the DPW point of contact, and the responsible Redstone Arsenal operations contractor.

In addition, each cellular RTU was programmed to log temperature measurements hourly, and to email this to MEC at midnight (Redstone Arsenal time). These daily emails served to continually verify that individual systems continued to function as designed. Table 1 shows when each pit's monitoring system was activated. Pits 4–6 were commissioned later than pits 2 and 7 because electric service for them had to be provided separately.

Table 1. Cellular-linked pit activation dates.

Pit Location	Date Active	Power Status
Pit C1	Never Active	No Power
Pit C2- T-Box 02	7/1/2010	Power
Pit C3- T-Box 03	10/13/2010	Power
Pit C4- T-Box 04	9/7/2011	Power
Pit C5- T-Box 05	9/8/2011	Delayed power activation
Pit C6- T-Box 06	9/12/2011	Delayed power activation
Pit C7- T-Box 07	6/30/2010	Power
Pit C8	Never Active	No Power

3 Discussion

3.1 Metrics

The benchmarks for assessing the effectiveness of the manhole remote sensing system were (1) continuous operation of the installed RTUs, (2) reliable interface between a manhole's sensors and its associated RTU, and (3) prompt automatic notification of temperature or water level alarms.

All pit RTUs were programmed to issue an alarm when a temperature sensor reported a value of at least 180 °F (82 °C), or when a water-level switch closed to indicate a flooded manhole.

3.2 Results

The project contractor began installing the sensors and RTUs for the 16 selected steam pits in June 2010. However, several difficulties developed that prevented the system from being initialized at that time. Some of the SEL-2411 RTUs were found to be defective on installation, so they had to be returned for repair. Also, not enough float switches were delivered to install in all of the test pits.

Three of the originally specified omnidirectional antennas installed to support the wireless Ethernet system for eight pits could not connect with the SCADA system repeater antenna due to their locations. Those antennas were replaced with directional Yagi antennas (see Figure 20). A larger problem for the wireless Ethernet system, however, was that Redstone facility-management priorities ultimately did not allow for the pits to be fully integrated into the SCADA system. Consequently, the project team was not able to conduct regular polling of the SCADA pits during the scheduled demonstration period.

A serious problem affecting the overall project was the unexpected lack of grid power availability near the selected manholes. It became evident early during project execution that not enough manholes had electric service to support the proposed number of pit installations. See section 3.3.1, "Lessons learned," for more.

3.2.1 SCADA-networked manholes

Resource issues at Redstone Arsenal demoted SCADA integration to a low priority, and the integration was not completed. Therefore, these manholes provided no remote data during the scheduled demonstration period. However, the system commissioning process did verify that the installed sensors in SCADA-monitored pits were correctly connected to the RTUs and that the RTUs could communicate with the SCADA network.

At six of the eight SCADA pits, a direct line of sight was established between the manhole antenna and the repeater antenna on Madkin Mountain. In two cases where the radio communications line of sight was blocked by structures, the directional antennas provided strong enough signals to communicate with the SCADA server despite the obstructions. But because none of these manholes was incorporated into the installation's SCADA network, they produced no data for the demonstration; all system performance data come from the cellular-networked manholes.

3.2.2 Cellular-networked manholes

After cellular-networked remote-sensing nodes were successfully commissioned, those connected with grid power performed as designed and expected during the demonstration period. Temperatures for all energized pits were reported daily. On occasions when the water level in pits was elevated, the appropriate water-level switches triggered an alarm and notified the assigned project and installation contractors as required.

The cellular pits were programmed to log temperatures hourly and to send daily summaries by email to the appropriate personnel. The purpose of this programming was to provide daily verification that the systems were continually operating. A sample of the data logged in the email notifications is shown in Figure 21. If desired, this demonstrated remote sensing application could be modified with little difficulty to output the data in a graphical format for related studies or longer-term manhole-condition tracking. Samples of general temperature trends for one of the pits, distributed over about 15 months, are shown Figure 22. One gap in the data due to a system outage is noted for early 2011. The other non-analyzed data indicated in the figure fell within the boundaries of the plotted trends, with no readings exceeding the alarm threshold value of 180 °F (82.2 °C) during the demonstration period.

Figure 21. Sample of raw data from lower and upper temperature sensors (in degrees Celsius.)

From: TBox TBOX02
To: MEC; CERL;
Cc:
Date: Wednesday, July 14, 2010 1:00:02 AM

T-Box 2
Lower Sensor:

Analog Input 4..20mA 0

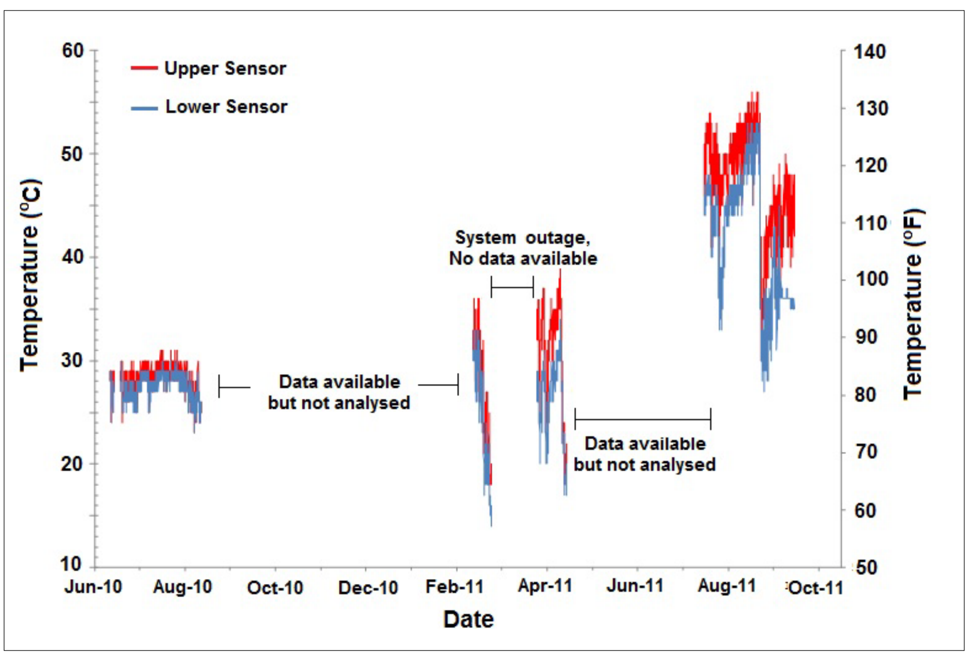
Index	Date	Time	Value
1	07-13-10	11:00:00 pm	26
2	07-13-10	10:00:00 pm	26
3	07-13-10	09:00:00 pm	27
4	07-13-10	08:00:00 pm	27
5	07-13-10	07:00:00 pm	27
6	07-13-10	06:00:00 pm	27
7	07-13-10	05:00:00 pm	27
8	07-13-10	04:00:00 pm	27
9	07-13-10	03:00:00 pm	27
10	07-13-10	02:00:00 pm	26
11	07-13-10	01:00:00 pm	26
12	07-13-10	12:00:00 pm	27
13	07-13-10	11:00:00 am	27
14	07-13-10	10:00:00 am	26
15	07-13-10	09:00:00 am	27
16	07-13-10	08:00:00 am	26
17	07-13-10	07:00:00 am	26
18	07-13-10	06:00:00 am	26
19	07-13-10	05:00:00 am	26
20	07-13-10	04:00:00 am	26
21	07-13-10	03:00:00 am	26
22	07-13-10	02:00:00 am	27
23	07-13-10	01:00:00 am	27
24	07-13-10	12:00:00 am	27

T-Box 2
Upper Sensor:

Analog Input 4..20mA 4

Index	Date	Time	Value
1	07-13-10	11:00:00 pm	27
2	07-13-10	10:00:00 pm	27
3	07-13-10	09:00:00 pm	27
4	07-13-10	08:00:00 pm	27
5	07-13-10	07:00:00 pm	27
6	07-13-10	06:00:00 pm	27
7	07-13-10	05:00:00 pm	28
8	07-13-10	04:00:00 pm	28
9	07-13-10	03:00:00 pm	27
10	07-13-10	02:00:00 pm	27
11	07-13-10	01:00:00 pm	26
12	07-13-10	12:00:00 pm	28
13	07-13-10	11:00:00 am	28
14	07-13-10	10:00:00 am	27
15	07-13-10	09:00:00 am	27
16	07-13-10	08:00:00 am	27
17	07-13-10	07:00:00 am	26
18	07-13-10	06:00:00 am	27
19	07-13-10	05:00:00 am	27
20	07-13-10	04:00:00 am	27
21	07-13-10	03:00:00 am	27
22	07-13-10	02:00:00 am	27
23	07-13-10	01:00:00 am	27
24	07-13-10	12:00:00 am	27

Figure 22. Sample data from T-Box 2 showing general temperature trends.



Water-level alarms triggered periodically in pits C2 and C7 (Table 2), for a total of seven and five occurrences for lower and upper sensors, respectively. Overall, most alarms were triggered after a period of rain, which is corroborated by weather data obtained from a commercial website. Local runoff can cause inflow that exceeds the capacity of manhole sump pumps to remove water over a short period of time, but precipitation cannot explain all of the level alarms issued in the sampled data. There does not appear to have been a clear trend associated with the dates of the level alarms. This means that there was probably no direct weather-related cause for at least some of the level alarms. Either they were caused by transient water-level increases for reasons unknown, or they were false alarms that would be diagnosed and addressed during the initialization period of a fully operational application.

Table 2. Level switch activity.

Pit Location	Lower Switch	Date/Time	Upper Switch	Date/Time	Precipitation Detail
C2	X	9/18/11, 0756			0.12 in. (link)
C7			X	10/10/10, 2245	0.10 and 0.11 in. (October 10 and 11, respectively; link)
C7	X	10/24/10, 2209	X	10/24/10, 2236	0.89 in. (October 25; link)
C7	X	11/29/10, 2315	X	11/29/10, 2326	0.39 in. (November 29–30; link)
C7	X	12/31/11, 2235	X	12/31/11, 2241	0.16 in reported (link)
C7	X	1/1/11, 0336			0.16 in. reported (link)
C7	X	1/3/11, 2154	X	1/3/11, 2209	No record of precipitation

3.3 Lessons learned

3.3.1 Manhole electric service availability

The importance of assuring that electric service is available at each network node (i.e., manhole) before system design was the central lesson in system. The availability of electric service cannot be assumed without an inspection of each networked manhole. If electrical power is not available, a firm plan and timeline for providing it must be developed before designing a sensor system. There were not enough steam pits at Redstone Arsenal with electrical service to support the initially planned number of pit installations. For future sensor deployments, electrical service must be verified before starting the project. Either grid power needs to be available at the manhole, or the location must provide enough sky exposure to support a photovoltaic power supply.

3.3.2 Wireless Ethernet issues

For installations using a wireless (radio frequency based) network that relies on line-of-sight telecommunications, a clear line of sight must be verified for all networked antennas before committing to that technology. Future construction projects must be considered in locating network antennas. During this project, two buildings were erected that obstructed previously confirmed lines of sight usable for wireless Ethernet communications with the SCADA network. Where a permanent direct line of sight cannot be assured, the project budget should include funding to support additional repeaters, or to elevate existing antennas on top of buildings, masts, etc., to route signals around obstructions.

3.3.3 Manhole physical constraints

The largest difficulty encountered during the installation was that the steam pits at Redstone Arsenal had different geometries, material quality, and steam line condition. A standardized installation schematic for all pits may not be feasible, so the design approach should be based on standard hardware components that can be adapted to each pit as needed. Alternately, candidate sites should be inspected early in the planning stage to determine whether the pits are uniform enough to allow for a standardized component layout.

It was not possible to find commercially available RTUs that could withstand the necessary range of temperatures and pressures inside heat distribution system manholes. Thus it was necessary to locate the RTU and associated hardware outside of the manhole. Even conduit that transitions from within the manhole to its exterior at the very top of the manhole must be able to withstand boiling temperatures. In at least one case, PVC conduit located at the top of a manhole softened and deformed significantly (Figure 23).

Figure 23. Deformed PVC conduit at top of manhole.

Once this project was under way, the project team learned about similar remote-monitoring efforts being undertaken by Consolidated Edison Company on their steam distribution systems in New York City (Low 2011). It was too late for the project team to work with them and apply any of their lessons learned. If future efforts are undertaken by the Army, the managers of such projects should refer to Low (2011) and consult with that research team as feasible. One useful result from that work was that the RTU equipment was mounted in shallow “valve box” type enclosures adjacent to, not inside, the manholes being monitored.

4 Economic Summary

4.1 Costs and assumptions

The standard manhole-inspection scenario includes a heat-distribution system that will experience heat loss significantly above original design values, intermittent boiling manholes, and premature manhole failure. The economic analysis of installing the type of system described here focuses on avoiding these costs. Accurate remote monitoring of manhole interior temperature and water level would provide the following benefits:

- Prompt notification of the need for critical repairs
- Avoidance of consequent additional damage that can result when the need for critical repairs is not promptly known
- Timely discovery and addressing of excess no-load heat losses, and prevention of the resulting wasted costs

This analysis assumes that every manhole at the installation site has an electric power supply to support operation of a sump pump, as required by Unified Facilities Guide Specification UFGS-33 60 00.00 10 (April 2008). Additionally, the analysis assumes that every manhole can be made accessible to a central monitoring and processing system using commercial, off-the-the-shelf wireless communications technology (e.g., cellular or radio-frequency [RF] based data links). System design, component selection, and installation methods are assumed to be properly matched to the site. Another assumption is that pit maintenance is performed promptly after a boiling manhole is detected.

A previous study (Marsh 1998) indicated that boiling manholes often go undetected for an average of one month. Assuming two pit failures per year, the result is a monthly cost of $4,327.16 in lost energy. Further costs can arise from damage to adjacent portions of the heat distribution system. A flooded manhole can cause the premature failure of adjacent system piping (an estimated 350 ft replaced every 5 years), at a cost of $750 per foot (Marsh 1998). With the remote monitoring system and alarms in place, it is assumed that repair of boiling pits and steam leaks will be more timely, thereby avoiding these damage-related costs.

For cellular communications, the total installed cost is calculated to be $5,648.12 per pit. This includes $72 for the first year's cellular service fee ($6 per month). This cost will recur for the life of the system. It also includes a cost for monitoring-system maintenance of 5% of total system cost; and a replacement cost for sump pumps of $300 each, assuming two failures per year. The costs for a cellular-based system are summarized in Table 3.

Table 3. Costs for cellular-connected system.

Item	Cost	Quantity	Extended Cost
T-Box Lite	$1,882.50	1	$1,882.50
GSM Antenna	$95.00	1	$95.00
Antenna Cable	$35.35	1	$35.35
Lightning Arrestor	$240.00	1	$240.00
Power Supply	$58.50	1	$58.50
Cable (T-Box - Lightning Arrestor)	$31.50	1	$31.50
Terminals, wires, etc.	$100.00	1	$100.00
Cell Activation, SIM Card	$39.95	1	$39.95
Monthly Cell	$6.00	12	$72.00
Temp Transmitter	$260.47	2	$520.94
RTD Temp Sensor	$193.55	2	$387.10
Enclosure	$82.48	1	$82.48
Level Switches	$33.60	2	$67.20
Sensor mounting, conduit, attachment, etc.	$200.00	1	$200.00
Installation labor	$1,835.60	1	$1,835.60
Total (per pit)			**$5,648.12**

Using an RF-based, wireless Ethernet SCADA link, the total installed cost is calculated to be $6,285.70 per pit. For the SCADA pit, the incremental cost of monitoring an additional node on an existing SCADA network is assumed to be zero. The details of the cost for this system are shown in Table 4.

Table 4. Costs for SCADA-networked system.

Item	Cost	Quantity	Extended Cost
SEL-2411	$1,374.00	1	$1,374.00
Enclosure	$395.00	1	$395.00
FreeWave Radio	$1,650.00	1	$1,650.00
Coax Jumper (from radio to lightning arrestor)	$30.00	1	$30.00
Lightning Arrestor	$55.00	1	$55.00
Cold Shrink Kit	$22.00	1	$22.00
Yagi Antenna	$140.00	1	$140.00
DIN mounting kit for radio	$35.00	1	$35.00
Antenna Cable	$95.00	1	$95.00
RTD sensor	$193.55	2	$387.10
Level Switch	$33.50	2	$67.00
Sensor mounting, conduit, attachment, etc.	$200.00	1	$200.00
Installation labor	$1,835.60	1	$1,835.60
Total (per pit)			**$6,285.70**

4.2 Projected return on investment (ROI)

The return on investment was calculated using methods specified in Office of Management and Budget Circular No. A-94, *Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs*. Table 5 shows the ROI calculation for the cellular-connected demonstration system (94.6), and Table 6 shows the ROI calculation for the SCADA-networked system (84.9). The estimated savings for using the cellular-based remote-monitoring system—roughly $534,000 over 30 years—greatly outweigh the modest equipment costs for installing and operating it.

Table 5. ROI calculation for cellular-connected system.

Return on Investment Calculation, Cellular

Investment Required			5,648
Return on Investment Ratio	94.60	Percent	9460%
Net Present Value of Costs and Benefits/Savings	39,534	573,841	534,307

A Future Year	B Baseline Costs	C Baseline Benefits/Savings	D New System Costs	E New System Benefits/Savings	F Present Value of Costs	G Present Value of Savings	H Total Present Value
1	600		3,186		2,978	561	-2,417
2	600		3,186		2,783	524	-2,259
3	600		3,186		2,601	490	-2,111
4	600		3,186		2,431	458	-1,973
5	600		3,186	262,500	2,272	187,590	185,319
6	600		3,186		2,123	400	-1,723
7	600		3,186		1,984	374	-1,610
8	600		3,186		1,854	349	-1,505
9	600		3,186		1,733	326	-1,407
10	600		3,186	262,500	1,619	133,734	132,114
11	600		3,186		1,514	285	-1,229
12	600		3,186		1,415	266	-1,148
13	600		3,186		1,322	249	-1,073
14	600		3,186		1,236	233	-1,003
15	600		3,186	262,500	1,155	95,347	94,193
16	600		3,186		1,079	203	-876
17	600		3,186		1,009	190	-819
18	600		3,186		943	178	-765
19	600		3,186		881	166	-715
20	600		3,186	262,500	823	67,985	67,162
21	600		3,186		769	145	-625
22	600		3,186		719	135	-584
23	600		3,186		672	127	-545
24	600		3,186		628	118	-510
25	600		3,186	262,500	587	48,463	47,876
26	600		3,186		549	103	-445
27	600		3,186		513	97	-416
28	600		3,186		479	90	-389
29	600		3,186		448	84	-364
30	600		3,186	262,500	419	34,571	34,153

Table 6. ROI for SCADA-networked system.

Return on Investment Calculation SCADA

Investment Required			6,286
Return on Investment Ratio	84.94	Percent	8494%
Net Present Value of Costs and Benefits/Savings	39,930	573,841	533,912

A Future Year	B Baseline Costs	C Baseline Benefits/Savings	D New System Costs	E New System Benefits/Savings	F Present Value of Costs	G Present Value of Savings	H Total Present Value
1	600		3,218		3,007	561	-2,447
2	600		3,218		2,810	524	-2,286
3	600		3,218		2,627	490	-2,137
4	600		3,218		2,455	458	-1,997
5	600		3,218	262,500	2,294	187,590	185,296
6	600		3,218		2,144	400	-1,744
7	600		3,218		2,004	374	-1,630
8	600		3,218		1,873	349	-1,524
9	600		3,218		1,750	326	-1,424
10	600		3,218	262,500	1,636	133,734	132,098
11	600		3,218		1,529	285	-1,244
12	600		3,218		1,429	266	-1,162
13	600		3,218		1,335	249	-1,086
14	600		3,218		1,248	233	-1,015
15	600		3,218	262,500	1,166	95,347	94,181
16	600		3,218		1,090	203	-887
17	600		3,218		1,019	190	-829
18	600		3,218		952	178	-775
19	600		3,218		890	166	-724
20	600		3,218	262,500	832	67,985	67,154
21	600		3,218		777	145	-632
22	600		3,218		726	135	-591
23	600		3,218		679	127	-552
24	600		3,218		634	118	-516
25	600		3,218	262,500	593	48,463	47,870
26	600		3,218		554	103	-451
27	600		3,218		518	97	-421
28	600		3,218		484	90	-394
29	600		3,218		452	84	-368
30	600		3,218	262,500	423	34,571	34,149

5 Conclusions and Recommendations

5.1 Conclusions

This project successfully demonstrated the design and operation of a remote monitoring technology for below-grade HDS manholes at Redstone Arsenal, AL. This technology uses robust temperature sensors and float switches selected to withstand and operate under excessive heat, humidity, and pressure conditions that are present in HDS manholes. Data from the sensor system are transmitted to maintenance personnel via remote transmitting units (RTUs) and wireless communication systems. The purpose of the system is to detect and report steam pipe leaks or manhole flooding that can quickly lead to high energy losses and system component damage. When flooded manholes or leaking steam pipes are detected and reported promptly, maintenance personnel can execute rapid repairs and prevent costly, long-term problems with the HDS.

The demonstration was designed to test two alternate wireless communication technologies—conventional GSM cellular data service and 900 MHz radio frequency wireless Ethernet integration with the installation's SCADA system.

The demonstration site posed several difficulties in the design and installation of the remote-sensing system. Grid electric service was not available at enough manholes, so several systems could not be made operational during the demonstration period. Also, the geography and layout of buildings at Redstone Arsenal made it difficult to set up 900 MHz radio frequency antennas at some manholes with a clear line of sight to the main repeater antenna on Madkin Mountain, which is critical to SCADA system integration. Although the antenna problems were solved and the wireless Ethernet system was successfully commissioned, the associated manholes were not fully integrated with the SCADA system due to resource-allocation decisions by the Redstone DPW.

Six of the eight manholes linked by GSM cellular technology had grid power during the demonstration period. Pit condition data were recorded and emailed to the designated point of contact daily to verify that the system was functioning as designed, and the ability to analyze these data was demonstrated.

It is concluded that the methods employed in this demonstration were successful as a proof of concept, and that a fully operational system can be designed and sustained using commercial off-the-shelf components. Planning and design must give due attention to

- a preliminary site inspection that assesses the existing HDS infrastructure to identify potential problems for system designers
- onsite inspection to confirm the availability of electric power at all selected manholes
- specification of the wireless communication technology that best suits the site's geography and built infrastructure.

5.2 Recommendations

5.2.1 Applicability

The technology demonstrated here would be applicable on any military or civilian property (e.g., medical complexes, college campuses, etc.) that uses a heat distribution system with manholes. Project results indicate that a stand-alone cellular-based design appears to be more practical than one that connects to an installation's SCADA system. Not only does SCADA utilization require higher-level management coordination to reliably implement, but it appears that SCADA also presents communication-security issues that were beyond the scope of this study to examine.

5.2.2 Implementation

This technology could be implemented throughout DoD by revising sections of Unified Facilities Guide Specification UFGS-33 61 01, *Valves, Piping, and Equipment in Valve Manholes*. Specifically, text and specifications would need to be updated in section 2.12.2, "High Level Alarm Indicator." Also, section 1.3.1, "Detail Drawings" (under section 1.3, "Quality Assurance"), should be updated to address sensor placement and working elevation. This update will be especially important with regard to the bottom elevation of the HDS piping.

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13. SUPPLEMENTARY NOTES

14. ABSTRACT

This project demonstrated a wireless remote-monitoring system for detecting and reporting steam leaks or flooding in underground heat-distribution system (HDS) manholes. The system immediately notifies maintenance personnel of critical conditions that could indicate expensive energy losses and potentially serious damage to the HDS. Demonstrated at Redstone Arsenal, AL, the system used durable temperature and water-level sensors for operating in very high heat and humidity. Remote-monitoring nodes included remote transmitting units using one of two alternate wireless data technologies. Wireless 900 MHz Ethernet service was installed and commissioned for eight manholes, linking them to the Redstone supervisory control and data acquisition (SCADA) system, but full integration with the SCADA system was not feasible given limitations on installation resources. Cellular data service was installed for six other manholes and commissioned successfully. Those nodes functioned for about 15 months to record ambient manhole conditions and email daily rollup data to the project point of contact (POC), verifying continuous operation.

The functionality of the system design was validated, but important lessons were learned about electric service availability, line-of-sight antenna positioning for wireless Ethernet, and RTU installation. The return on investment for the cellular system was 94.6, potentially saving $534,000 in maintenance over 30 years.

15. SUBJECT TERMS

Corrosion prevention program (CPC), heat distribution system, remote sensing, remote transmitting unit (RTU)

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